FIEF Working Paper Series 1999 ISSN 1651-0852

No. 153

Work Morale and Economic Growth*

by

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Abstract

We present a growth model in which the work morale of R&D workers is endogenously determined by fair wage considerations and show that increases in endowments of researchers do not necessarily have positive growth effects. The results is in line with the empirical observations that the very large increases in the number of R&D workers during the last 30 years have not generated the growth rates predicted by the basic endogenous growth models. Moreover, a number of mechanisms are present in the model that counteract the positive growth effects of higher education and which do not show up in growth models based on competitive wage setting.

Keywords: Efficiency wages; Fairness; Growth
JEL codes: J41; O4?

July ?, 1999

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*I have benefited from discussions with J. Agell at an initial stage of the paper and from a seminar at FIEF.

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1. Introduction

The growth literature is much focused on the incentives that firms have to invest in R&D. The studies typically investigate the effects of, for instance, factor supply changes, R&D subsidies, etc., on the inputs of R&D workers in the growth process. A closely related, yet neglected, issue concerns the incentives that the individual R&D workers have to perform well. This neglect in the literature is most surprising since many growth models describe researchers as participants in R&D races between firms and these researchers' work morale then stands out both as an important source of success to the firm and an engine of growth to the economy. Firms' dependence on the research staff implies strong incentives to introduce compensation policies that would stimulate R&D workers to perform well and, not surprisingly, a large literature on this issue has arisen.

Allowing for variations in the individual R&D worker's effort could potentially help explain important stylized facts which are the focus of many recent theoretical growth studies. One such fact is that the observed dramatic increases in the employment of R&D workers like scientists and engineers, have not yielded the increases in economic growth rates that are predicted by the basic endogenous growth models. While workers engaged in research have almost doubled in the US and increased at similar rates in many other developed countries during the last thirty years, per capita growth rates have been constant or even declined.[1]

Several theoretical explanations to these empirical observations have been offered, all based on modifying the scale assumptions of basic growth models. Jones (1995b) shows that a Romer model modified for the scale effects can account for the fact that economic growth has not accelerated to the rates predicted by basic endogenous growth theory. The elimination of the scale effects induces, however, a return to models based on exogenous growth in the Solow spirit. To allow for sustained growth, Young (1998) modifies the Grossman-Helpman "quality ladders" model by allowing for an endogenous degree of product variety and finds that rent dissipation through product proliferation could lower growth. Also starting with the "quality ladders" model, Segerstrom (1999) shows that a model that allows for R&D to become

[1] See Jones (1995a) for an extended discussion.

increasingly more difficult over time yields predictions that are theoretically consistent with these basic observations including observations on constant number of patents. Similar conclusions are obtained in Kortum (1997).

The present study offers another and quite different explanation that may serve as another piece to add to the puzzle: Introducing endogenous work morale in a basic growth model we find that there need no longer be positive growth effects of increases in the number of R&D workers.

Another stylized fact, noted by Jones (1995a) is that, for the OECD countries, human capital formation trends upwards while growth rates do not. In line with this observation, our model reveals a number of effects that tend to counteract growth when workers go to higher education and which growth models based on competitive wage setting are unable to capture. Several forces reduce effort and increase the under utilization rate of R&D workers as human capital formation increases.

Much empirical research has been devoted to the determinants of workers' effort and these empirical findings appear consistent enough to serve as a basis for theoretical studies on the relation between work morale and economic growth. One important line of this research, for which empirical support is adding up at a fast pace, is based on sociological and psychological notions of ”fair wage” motivations among workers as determinants of work effort. In evaluating a large set of labor market theories on pay by means of interviews with 300 business people, labor leaders and counselors of unemployed, Bewley (1998) finds much support for the ”fair wage” version of efficiency wage theory developed by George Akerlof and Robert Solow, while almost all other modern labor market theories tend to get rejected. The fair wage efficiency wage model is also supported by a large number of other studies like Blinder and Choi (1990) for the US, Kaufman (1984) for the UK, Agell and Lundborg (1995a) for Sweden, Campbell and Kamlani (1997) for the US. All theses studies are based on interviews (or questionnaires) with the people that actually set the wages in firms. Interestingly, support for this model is also obtained by Fehr and Falk (1999) using an experimental approach.[2]

The highly consistent messages of these studies, carried out in countries with highly diverging labor market institutions (like the US, UK and Sweden) and based on different methods (like interviews or questionnaires, and experiments) justifies the specification of a basic growth model on the principal finding that fair wage considerations determine effort of R&D workers. With the modern firms' dependence on R&D workers' performance in mind, we introduce these aspects into a Grossman-Helpman (1991a) quality ladders endogenous growth model.

Efficiency wage setting can be argued to be of particular relevance to groups of workers like researchers, civil engineers and others that are directly involved in improving the quality of goods. First, efficiency wage setting assumes that workers have some latitude in determining their own effort. This assumption seems particularly easy to accept for R&D workers since their effort is not determined by technological factors as sometimes is the case for workers on the assembly line or factory floor.

Secondly, it stands without reason that the performance of individual researchers must be crucial to the performance of the firm. Without any breakthroughs in the research lab of the medical company or in the designs of new cars in the auto company, these firms' possibilities to survive are threatened in the long run. The likelihood of a research breakthrough, in turn, hinges on the incentives that R&D workers have to work hard. Therefore, it is not surprising that the empirical literature mentioned above shows that management is most concerned with maintaining good relations with workers as a way to keep workers' effort up.[3] To maintain positive relations and high effort, we assume that firms offer R&D workers a fair share of the expected returns to winning a R&D race. This is not only a natural reference of fairness to the individual R&D worker (besides relative wages and unemployment), but from the firm's perspective it also offers the right incentives for the R&D workers to make a research breakthrough that will benefit the firm.

Section 2 presents the building blocs of the model and derives the system of equations to be used. Comparative static results are presented and evaluated in section 3 and the final section offers some concluding remarks.

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[2] See also Akerlof (1982) for sociological and psychological evidence on the importance of the fair wage hypothesis.
[3] See in particular Campbell and Kamlani (1997).

2 The Model

Some general comments

We assume a continuum of industries that are indexed by T , [0,1]. Firms participate in R&D races that lead to quality improvements. In each industry, firms are distinguished by quality *j* of the products they manufacture. The higher value of *j* the higher is the quality and *j* takes on only integer values. At time *t*=0, the state-of-the-art quality product in any industry is *j*=0, i.e., there is one firm in which the production workers know how to manufacture a product of quality *j*=0 but no workers in any firm knows how to produce a product of a higher quality. The R&D workers' innovation implies that the firm acquires the ability to manufacture a higher quality product. If the state-of-the-art quality in an industry is *j*, the next firm to win a R&D race becomes the single manufacturer of a *j*+1 quality product. Firms are Bertrand price-setters. Hence, a winner of a R&D race can price lower quality competitors out of business and take over the market in its industry. Over time, as new innovations push industries up the quality ladder the economy grows. These are the basic ideas of the Grossman-Helpman (1991a) growth model.

Labor is, in our model, of two kinds: R&D workers, L_r , and production workers, L_p , which both are in fixed supplies. While R&D workers can work as production workers, production workers cannot work as R&D workers. One unit of production workers is required to produce one unit of output, regardless of quality. We treat the wage rate of production workers as the numeraire and let w denote the relative wage of R&D workers.

Utility maximization and fair wages

All consumers live forever and have identical preferences. They maximize discounted utility:

$$U \equiv \int_0^\infty e^{-rt} \log U^s(t)dt, \qquad (1)$$

where D is the subjective rate of discount and $\log U^s(t)$ is each consumer's static utility at time t, which is given by:

$$\log\ U^s(t) \equiv \int_0^1 \log \sum_j \lambda^j d(j,t,\omega) \ +\ \log U^e(e(t)). \qquad (2)$$

The first term represents consumption decisions where d(j, t, ω) denotes the quantity consumed of a product of quality *j* produced in industry ω at time *t*. The parameter $\lambda>1$ represents the extent to which higher quality products improve on lower quality products, i.e., the size of the step on the quality ladder.

The second term applies to R&D workers only and represents effort and is zero for production workers and asset holders.[4] Utility is affected by the actual effort $e(t)$, which is determined by the optimizing individual R&D worker. The term represents the decision to supply work effort and reflects the fair wage considerations.

To determine e, we first assume that the individual R&D worker compares his wage to that of the production workers, w_p, which is in line with basic efficiency wage theory. 13.3 percent of firms in Campbell and Kamlani (1997) claim that high wages are the most important factor to stimulate effort of white collar workers.

Secondly, we may note that Campbell and Kamlani also find a strong link between the firm's profits and workers' perceived fair wage.[5] They also report that two thirds of US firms claim that "Good management-worker relationships" is the most important factor to stimulate white collar workers' work morale. Considering that profits is a crucial element in the expected returns to winning a R&D race, a natural way to create good relationships to R&D workers is to offer them what they consider to be a fair share of the expected returns, u. We shall later define this variable but for the time being it suffices to note that the individual R&D worker takes this expected reward as given in the utility maximization process.

Thirdly, we assume that some share of the R&D workers is relegated to the factory floor. Since this share in efficiency wage models is formally identical to the unemployment rate, we represent this under utilization rate by u. This is the share of

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[4] We do not extend the assumption of fair wage considerations to production workers. Although this may seem to go against empirical findings, assuming that production workers' effort also depends on fair wage considerations is hardly warranted since, as argued, the growth of the firm, which is what we focus on, hinges on R&D workers' rather than production workers' effort. Indeed, if production workers are encompassed by the insight that the firm's growth and probability of winning R&D races hinge on researchers' efforts, fair wages for production workers becomes a highly complex issue. The added complexity that an assumption of variable effort among production workers would give rise to, would in turn make the model intractable.

R&D workers that is unemployed in their capacity as R&D workers. The unemployment rate is a standard argument in efficiency wage theory and almost ten percent of the firms in the Campbell and Kamlani study claim that high unemployment is the most important factor that raises effort. Our effort function is specified, on a general form, as[6]

$$e_i = e_i(\frac{w_i}{w_p}, \frac{w_i}{u}, u)\,. \qquad (3)$$

Let e* denote the optimal level of effort that obtains by solving equation (3) for the optimum values of w_i, u, and u. (w_p will be normalized to 1.) We assume a concave utility function U^e such that $\log U^e = 0$ for e = e*, else $\log U^e \pi\ 0$ which implies that, in optimum when researchers have set their effort e=e*, all utility derives from commodity consumption.[7]

We may think of U^e as a function where the equilibrium effort determines the work norm and any deviation in either direction from the work norm generates disutility. An important thing to note is that comparative static changes in the model yield different equilibrium effort levels and hence imply different work norms. It is only deviations from the norms in the two cases that negatively affect utility U^e. That workers adjust to the norm is one reason why firms sometimes replace poorly performing workers to let them work in teams where the workers' norms imply a higher work morale.

At each point in time t, each consumer allocates expenditure E to maximize log $u(t)$ given the prevailing market prices. Solving this budget allocation problem yields a unit elastic demand function

$$d = E / p, \qquad (4)$$

where d is quantity demanded and p is the market price for the product in each industry with the lowest quality adjusted price. The quantity demanded for all other products is zero.

R&D workers also determine their optimal effort level. Since their static utility is

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[5] See Campbell and Kamlani, (1997) p. 775 and p. 785.

[6] For derivation of effort functions see the seminal study by Akerlof (1982) and for extended versions similar to the one presented here, see Agell and Lundborg (1995b).

[7] It seems natural to assume that the individual R&D worker compares his wage to other R&D workers, i.e. that w_i / w should be included as an argument. With homogeneous R&D workers, this yields a unit

additively separable and since the optimal effort level depends on wage formation institutions, we return to the question of optimal effort later in the paper.

Given this static demand behavior, each consumer chooses the path of expenditure over time to maximize (1) subject to the usual inter-temporal budget constraint. Solving this optimal control problem yields[8]

$$\frac{dE(t)}{dt} / E(t) = r(t) - r, \qquad (5)$$

that is, a constant expenditure path is optimal if and only if the market interest rate , r , equals r . As we restrict attention to steady state properties of the model, r is the equilibrium interest rate throughout time and consumer expenditure is constant over time. We let E denote aggregate steady state consumer expenditures.

The Behavior of Firms

a) The product market

One unit of labor produces one unit of output regardless of quality. Since production workers' wage rate has been normalized to one, every firm has a constant marginal cost equal to one. When the researchers have innovated, the firm becomes the single quality leader in its industry. Hence, whenever innovation occurs, the identity of industry leaders changes.

We consider now the profits earned by a firm that has innovated successfully and become the leader. With the follower charging a price of w_p, which we normalize to unity, the lowest price such that losses are avoided, the new quality leader earns instantaneous profits

$$p\ (p) = \begin{cases} (p-1)E\ / p, & p \leq l \\ 0, & p \ \phi\ l \end{cases} \qquad (6)$$

where p is the price set by the market leader. Equation (6) implies that profits are maximized by choosing $p = l$. Therefore, this quality leader earns as a reward for its innovative activity a profit flow equal to (1-1/ l) E . None of the other firms in the industry can do any better than break even by selling nothing at all.

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value in the effort function after the first order condition has been derived and has no real influence on the model. Cf. Agell and Lundborg (1995b).

b) R&D inputs.

The returns to engaging in R&D are independently distributed across industries and over time. In industry T at time t, we let R denote the number of R&D workers employed by firm i. What matters to us is the employment of R&D workers in efficiency units, i.e. $e_i\lambda_i$. We let $e\lambda = \sum_i e_i\lambda_i$ denote the industry-wide R&D employment in efficiency units. The *instantaneous* probability that some firm will be rewarded for R&D success is assumed to be $e\lambda$. Individual R&D firms behave competitively and treat R as given, not influenced by their choice of R.

Let L denote the expected discounted rewards for winning an R&D race and let s denote the government's R&D subsidy rate. For a given effort e_i, each firm chooses its R&D employment λ_i to maximize instantaneous profits that equal $ue_i\lambda_i - w(1-s)\lambda_i$. For a steady state profit maximization equilibrium, the optimal level of inputs of R&D workers implies that $u = w(1-s)/e$.

What are the rewards for winning R&D races? We know from equation (5) that in any steady state equilibrium the market interest rate must equal r. The future profits must first be discounted by r, but we must also consider that a quality leader eventually is driven out of business by other firms' further innovations. This occurs with instantaneous probability $e\lambda$ during time span dt. Thus we obtain as an equilibrium R&D condition that u equals:

$$\frac{(1-\frac{1}{l})E}{r+e\lambda} = \frac{w(1-s)}{e}. \qquad (7)$$

On the left hand side we have, in the numerator, the future profits. These are first discounted by means of r but the second term in the denominator captures that, in equilibrium, leaders are eventually driven out of business by further innovation since the instantaneous probability also appears in the denominator. The right hand side represents the costs.

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[8] See Grossman and Helpman (1991a).

c) Firms' wage setting and the equilibrium effort.

R&D workers supply effort at a rate that is affected by their wage rate in comparison to the wage of production workers and to the expected returns to winning a R&D race which the R&D workers are involved in, as in equation (3). We then study efficiency wage setting for the R&D workers, given the level of R&D workers employed, λ_i. Firms set the wage so as to extract more effort out of the individual R&D worker i taking all other workers' effort as given. Throughout the paper we assume that production workers' wages are set competitively.

Taking the R&D inputs and the expected returns to winning an R&D race as given, the firm then determines the wage w_i to minimize the wage per efficiency units of individual i. From (3) firms minimize $w_i / e_i(\frac{w_i}{w_p}, \frac{w_i}{u}, u)$, subject to $e_i \pi 0$ for $w_i = 0$.

The first order condition, $e - w_i(e_1 \frac{1}{w_p} + e_2 \frac{1}{u}) = 0$, implies that

$$\mathbf{e}^{e}_{w/w_p} + \mathbf{e}^{e}_{w/u} = 1 \qquad (8)$$

where $\mathbf{e}^{e}_{w/w_p}$ is the elasticity of effort with respect to an increase in w / w_p and $\mathbf{e}^{e}_{w/u}$ is the elasticity of effort with respect to an increase in w / u. This differs from the standard Solow condition $\mathbf{e}^{e}_{w} = 1$ simply by that the sum of the two elasticities must equal unity in equilibrium. After having assumed identical wages for all R&D workers, i.e. $w_i = w$, set w_p to unity, and used the fact that $u = w(1-s)/e$, the effort function reduces to

$$e = e(w, (1-s), u) \qquad (9)$$

where effort rises in all three arguments. With the equilibrium wage and under utilization rate, (9) yields the optimal effort rate.

Labor Markets

We assume that R&D workers can work in the lab and on the factory floor while production workers only can work on the factory floor, but not in the lab. If demand for R&D workers drop, R&D workers are driven down on the factory floor and have to accept lower pay.[9] With $w_p = 1$, each leader employs E / 8 workers for production. Full employment in the labor market for production workers then implies that

$$L_p + uL_r = E / l, \qquad (10)$$

holds. Supply of labor for production, i.e. the fixed supply of production labor, L_p, plus the number of workers that are not hired in the R&D lab, uL_r, equals demand for labor. As firms do R&D they demand R workers per industry. Thus, full employment of R&D labor in terms of number of workers $(1-u)L_r$ implies that

$$(1-u)L_r = \lambda. \qquad (11)$$

Expenditures

Steady state consumer expenditure E must equal total wage incomes plus interest income on assets owned minus taxes paid to finance the R&D subsidy. The value of all assets equals the stock market value of all leader firms, i.e. $u = w(1-s)/e$ in equilibrium. Then ru are the interest incomes.

To determine the amounts of taxes that should be raised to finance the R&D subsidies, we note that $(1-u)L_r$ workers do R&D. These workers are paid $w(1-u)L_r$ and the government pays the fraction s of this wage bill. Thus the government must raise $sw(1-u)L_r$ in taxes to finance the R&D subsidy. Putting this all together, consumer expenditures become

$$E = L_p + uL_r + w(1-u)L_r + rw(1-s)/e - sw(1-u)L_r. \qquad (12)$$

We now have six equations that constitute the basic model: one R&D equilibrium condition (7), one wage setting equation (8), one effort equation (9), one production labor market condition (10), one R&D labor market equilibrium condition (11), and one expenditure condition (12). These six equations determine five variables w, e, E, λ and u. However, it is easily checked that equation (12) is implied by the other five equations so that this equation may be dropped.

For the understanding of the mechanics of the model it may be useful to discuss its

[9] We could have assumed that R&D workers get unemployed. However, with competitive wages for production workers they would be fully employed and it seems to go against empirical facts to have unemployment among researchers and full employment among production workers.

solution. Assume a given number of R&D workers in the lab, λ. Together with equation (11) this gives the share of R&D workers at the factory floor, u, and with knowledge about this share we get the wage rate, w, and the effort level, e, from equations (8) and (9). We may also determine expenditures, E, in equation (10). Finally, with a value of expenditures, we may determine the equilibrium number of R&D workers, λ, from (7). Besides these simultaneously determined endogenous variables, the model then straightforwardly determines a number of other variables that are of central interest and to which we now turn.

Welfare and Growth

We calculate consumer welfare, i.e. discounted consumer utility, starting from time t=0. Remember that all consumers are assumed to have identical preferences. Consider first the utility of a consumer with steady state expenditure denoted e. At any point in time, this consumer only buys the highest quality product in each industry, and from (3), this consumer's static demand function is given by d(j,t,T)= e /p(j,t,T). This consumer buys from a leader charging the price l. Before we substitute this information into (2) we note that, in this equation, $\int_0^1 \log\ l dw = tI \log\ l$ where I is the steady state industry-wide instantaneous probability of R&D success.[10] The instantaneous probability of R&D success is $e\lambda$. Substituting all the above information into (2) yields the consumer's instantaneous utility

$$\log U^s(t) = te\lambda \log\ l. \qquad (13)$$

The time derivatives of log U^s(t) is then $g = e\lambda \log\ l$ which therefore represents the growth rate of utility. (Remember that utility derived from the effort part for R&D workers in equation (2) is zero at optimum effort e*.)

Real Gross National Product

Nominal gross national product is in the model equal to consumption and since consumption is identical to consumer expenditures, we have that GNP=E. In a steady-state equilibrium nominal GNP does not change over time.

However, growth implies that *real* GNP rises over time as the quality of the products improve. With nominal GNP constant in steady-state, we must have deflation in terms of the quality adjusted (real) price. With the R&D intensity $e\lambda$, a typical R&D race has time duration equal to its inverse $\frac{1}{e\lambda}$. The relationship between the quality-adjusted price after the innovation (P_{ra}) and before the innovation (P_{rb}) is $P_{ra} = P_{rb} / 8$. It follows that a real price index $P_r(t)$ must satisfy $P_r(\frac{1}{e\lambda}) = 1/8\, P_r(0) = P_r(0)\exp[A(\frac{a}{e\lambda})]$ where A represents the inflation rate. Solving yields the quality adjusted inflation rate as $A = -e\lambda \log 8$. To simplify, assume that the price index takes on a unity value at time t=0. The real GNP at time t equals $E/P_r(t)$, or

$$GNP_r = E \ \exp(te\lambda \log \ l). \tag{14}$$

Hence, real GNP grows at the utility growth rate in (13), $g = e\lambda \log \ l$. The growth rate is made up of the product of the instantaneous probability of winning a race and log l, i.e. the increase in the quality of goods that follow from a research breakthrough. Note also that the growth rate of utility and real GNP is identical to the rate of deflation.

To evaluate overall consumer welfare, we set $e = E$. Substituting (13) into (1) we get $W \equiv rU = (e\lambda \log \ l\,)/\, r + \log(E \ / \ l\,)$ where W denotes the welfare level. Moreover, merging g with this expression, and utilizing (4) and the fact that $p = l$, we find that welfare is

$$W = g \,/\, r + \log(E \,/\, l)) = g \,/\, r + \log d \tag{15}$$

i.e. the sum of discounted growth and static demand. To obtain the welfare effects, we need to consider, besides growth, also expenditures.

3. Comparative Static Results.

We turn now to an evaluation of the comparative static effects. The equation system (7) through (11) may be simplified further. Solving for E in (10) and plugging the result into (7) and similarly eliminating λ, yields a three equation system that solves for w, e and u and the formal derivations are presented in appendix. Below we discuss the main results.

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[10] See Grossman and Helpman (1991a, p. 50).

Effects of increases in R&D workers

We first investigate the effects of an increase in the number of R&D workers. We can think of this case either as a policy that raises the number of skilled in the native labor force or as an immigration quota of high skilled workers, of course without consideration of the effects on the emigration country.[11] First, an increase in the supply of R&D workers, L_r, unambiguously raises expenditures which raises demand for goods and for production workers. But since profits rise in expenditures (equation (7)), it also tends to raise demand for R&D workers. The net effect of increases in demand for both types of workers is an increase in the share of R&D workers employed in production, i.e. an increase in the under utilization rate of R&D workers, u. Formally, we get :

$$\frac{du}{dL_r} = K(e_1 - \frac{de}{dw}) \phi 0, \qquad (16)$$

where $K = (\, l - 1)(u\frac{r}{e} - (1-u)L_p) / D(\frac{r}{e} + (1-u)L_r)^2 < 0$ and where D is the positively signed determinant (see appendix). Note that e_1 is the partial effect of an increase in effort of a wage increase in equation (8), while $\frac{de}{dw}$ is the total effect on effort of a wage hike in equation (9) and that $\frac{de}{dw} > e_1$.

The increase in the under utilization rate of R&D workers implies that the risk of being forced to work at a lower wage as a production worker rises, and from basic efficiency wage theory, effort goes up, as seen in (9). However, this effort increase gives the firms incentives to adjust the wage to fulfill the wage setting condition (8) and having been offered higher effort as a windfall gain, firms will naturally lower the wage rate:

$$\frac{dw}{dL_r} = K\frac{de}{du} \pi 0. \qquad (17)$$

This, in turn, tends to reduce effort in the new equilibrium. As the R&D workers have experienced an increase in the share of workers going to the factory floor, which raises effort, and a wage decrease, which lowers effort, we need to determine the net effect.

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[11] For an analysis of the effects of immigration on growth in a two-country setting, see Lundborg and Segerstrom (1999).

This comes out negative:

$$\frac{de}{dL_r} = e_1 K \frac{de}{du} < 0 . \qquad (18)$$

The increased availability of R&D workers will raise the absolute number of R&D workers in production (via higher u) as well as in the lab. The effect on the number of R&D workers in the lab is:

$$\frac{d\lambda}{dL_r} = (1-u) - L_r \frac{du}{dL_r} > 0 . \qquad (19)$$

R&D inputs will increase by $(1-u)$ but since u rises an increasing share of R&D workers will be under utilized.

With the effects on R&D inputs and on effort, we are ready to consider the growth effects. We have $g = e\lambda \log\, l$ from which we get:

$$\frac{dg}{dL_r} = \frac{g}{L_r}\left[e^{e}_{L_r} + e^{\lambda}_{L_r} \right] \qquad (20)$$

implying that more R&D workers will raise growth as long as the absolute value of the (negative) elasticity of e with respect to L_r, $e^{e}_{L_r}$, is not larger than the (positive) elasticity of λ with respect to L_r, $e^{\lambda}_{L_r}$. The growth effect cannot be signed on theoretical grounds and we cannot rule out the possibility that the drop in effort is of such a magnitude that it outweighs the increase in the number of R&D workers and hence that a larger supply of R&D workers inhibits growth. Yet, one might expect only a small decrease in effort that cannot compensate for the increase in R&D inputs so that growth is stimulated.

However, even if growth rises, we cannot be sure that welfare rises. As is clear from (15) also expenditures, i.e. current consumption, must be taken into consideration. We get the effect on expenditure per worker as

$$\frac{dE^{w}}{dL_r} = \left(\frac{dE}{dL_r} - \frac{E}{L_r + L_p}\right) / \left(L_r + L_p\right) \gtrless 0. \qquad (21)$$

Hence, a larger number of R&D workers has ambiguous effects on expenditures per worker. If the marginal effect on expenditures is larger than average expenditures, an increase in R&D workers raises expenditures per worker and hence also tends to raise welfare per worker. The actual outcome depends on the effects of the increase in R&D

workers on the wage, under utilization as well as effort. Since the R&D workers' wage relative the production workers' is high, we expect that expenditures per worker rises, which, in turn, implies that the increase in R&D workers has a positive effect on welfare per worker via expenditures. To sum up, while both the growth and the expenditure effects are theoretically ambiguous, we have reason to believe that the positive effects dominate and that an increase in the number of R&D workers raises welfare per worker.

Effects of increases in the number of production workers

It is natural to compare the effects of increases in R&D workers to those of an increase in production workers. This can be thought of either as an increase in the native unskilled labor force, or as the effects of an immigration quota for production (unskilled) workers. Also in this case expenditures rise which increases profits of firms (equation (7)) and for the R&D equilibrium condition to be fulfilled, the number of R&D workers in the labs should rise. Indeed, we find that the rate of under utilization of R&D workers drops:

$$\frac{du}{dL_p} = R\left\{e_1 - \frac{\partial e}{\partial w}\right\} \pi\ 0. \qquad (22)$$

where $R = \frac{l-1}{D\left(\frac{r}{e}+\lambda\right)}$ >0. Equation (22) implies that the increase in production workers releases a number of R&D workers that go back to the lab. The drop in under utilization of R&D workers moreover tends to reduce effort and to counteract this "windfall loss", firms raise the wage until the modified Solow condition is fulfilled. The effect on the wage is:

$$\frac{dw}{dL_p} = R\frac{\partial e}{\partial u} \phi\ 0. \qquad (23)$$

This wage increase in turn raises effort and the net effect is an increase in effort:

$$\frac{de}{dL_p} = \mathrm{Re}_1\frac{\partial e}{\partial u} = e_1\frac{du}{dL_p} \phi\ 0. \quad (24)$$

From (11) we know that the decrease in u implies that the number of R&D workers employed in the labs must go up:

$$\frac{d\lambda}{dL_p} = -L_r \frac{du}{dL_p} \phi\ 0. \qquad (25)$$

Thus, as the number of production workers increases, firms will employ more R&D workers in the lab and less R&D workers will be demanded at the factory floor. This spill-over effect tends to stimulate growth. At the same time, effort among the individual R&D workers rises and both effects should have positive growth effects. The growth effects obtain from differentiation of $g = e\lambda \log\ l$ as

$$\frac{dg}{dL_p} = \frac{g}{L_p}\left[e^{e}_{L_p} + e^{\lambda}_{L_p}\right] > 0. \qquad (26)$$

Hence, there are unambiguously positive growth effects of more production workers. This is in contrast to the case of an increase in R&D workers which lowers growth if the effort effect is low enough.

To evaluate the welfare effects we need to consider again the expenditure effects. As for increases in R&D workers there is a positive welfare effect as expenditures, and hence consumption, rises. However, as for the effects of an increase in the number of R&D workers, the effects on welfare per worker are ambiguous as the number of production workers increases. This is shown by differentiating expenditures per worker with respect to L_p and an expression corresponding to (21) obtains:

$$\frac{dE^w}{dL_p} = \left(\frac{dE}{dL_p} - \frac{E}{L_r + L_p}\right) / (L_r + L_p) \frac{\phi}{\pi} 0. \qquad (27)$$

If the marginal effect on expenditures is larger than the average effect, an increase in the number of production workers will raise expenditures per worker and contribute to raising welfare per worker above that caused by the higher growth rate. Since production workers wage is lower than R&D workers' wage, we could expect a drop in per worker expenditures such that welfare per worker would tend to go down.

Can we conclude that increases in the number of production workers have better potential to raise growth and welfare than increases in the number of R&D workers? No, this would be a premature conclusion. It is true that an increase in R&D workers lowers effort in the model and that increases in production workers raise effort which supports such a conclusion. However, we should remember that the increase in the number of R&D workers has an impact effect on R&D inputs of $1\text{-}u$ while a corresponding effect is not present as production workers rise in number. In the latter case, increases in R&D inputs only come about via the adjustment in terms of a lowered u. As implied by equation (11) there is a direct positive effect on λ of increases in L_r and a indirect negative effect via u while there is only an indirect positive effect on λ of increases in L_p. Yet, as compared to static models of immigration that lead to the conclusion that immigration of skilled workers is preferable to immigration of unskilled, the present model must be said to cast considerable doubts on the generality of such a conclusion.

Effects of higher education.

It is straightforward to extend the above arguments by investigating the effects of education, i.e. to see what happens if production workers transform, via free education, into R&D workers. We do not intend here to offer a model of endogenous human capital formation since we have assumed that workers are born either with a skill to learn and do R&D or not born with this skill. Our purpose is consequently limited to showing the quite unexpected effects of a production worker who one morning wakes up with the skill to do R&D and therefore gets employed at the lab instead of at the factory floor.[12]

If we increase L_r and decrease L_p, we first note that the share of R&D workers that is relegated to the factory floor increases; both the increase in L_r and the decrease in L_p tend to increase the under utilization rate and this will counteract the initial positive effects of the increase in R&D workers. The increased under utilization rate drives up research effort. On the other hand, we have shown that both the increase in L_r as well as the decrease in L_p have negative effects on the relative wage of R&D workers and the downward wage pressure unambiguously reduces effort. The net effect on effort as L_r increases and the net effect on effort as L_p decreases were previously shown to be negative so that we have an unambiguously negative effort effect.

The most interesting effects occur on the growth rate of the economy. As noted, growth is the added effects of changes in effort and R&D quantities. First, effort drops

[12] Endogenous human capital formation has been studied notably in Lucas (1988) and Grossman and Helpman (1991b).

since increases in R&D workers and decreases in production workers both have this effect. The increase in R&D workers raises λ by $(1\text{-}u)$ as a direct effect but also lowers λ since u, the under utilization rate, rises. Moreover, the decrease in production workers unambiguously *increases* the under utilization rate. Thus, while there is one positive effect on the growth rate, this is counteracted by two negative effects on work morale and two effects that tend to reduce growth via a lower utilization rate of R&D workers. This gives surprisingly strong reasons to question that education has such strong growth effects that often are claimed. These negative effects would not appear in standard competitive models where effort (implicitly) is constant and all R&D workers are fully utilized. The competitive model would only capture the positive effects in terms of higher inputs of R&D.[13] Remember also that we have suppressed all costs involved in educating a production worker to a researcher.[14]

Effects of subsidies

Can economic policy stimulate growth and welfare? The purpose of an R&D subsidy is to support firms' R&D activities by lowering the costs. To see if this is the case, we first study how firms allocate R&D workers between the lab and the factory floor. The effect on the under utilization rate is

$$\frac{du}{ds} = \frac{1}{D}\left\{(\frac{\partial e}{\partial s} + \frac{e_2}{[1-s]^2})(1-s) - (\frac{\partial e}{\partial s}e_1 + \frac{e_2}{[1-s]^2}\frac{\partial e}{\partial w})Q + w(e_1 - \frac{\partial e}{\partial w})\right\} \pi\ 0 \quad (28)$$

where $Q = \frac{r}{e^2}(\,l-1)(L_p + uL_r)/(\frac{r}{e} + (1-u)L_r)^2 > 0$. Equation (28) implies, together with (11), that the number of R&D workers in the lab rises. For equation (12) to be fulfilled, expenditures must come down (via higher taxes).

As the under utilization rate drops, effort tends to go down (equation (9)). Following this shift, firms must reconsider the wage rate and to fulfill the equilibrium condition (8), the wage will be revised upwards:

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[13] Cf. Grossman and Helpman (1991b).

[14] We have not endogenized the education decision but the qualitative effects we obtain in the model in no way hinge on the equilibrium conditions of the marginal production worker who becomes skilled.

$$\frac{dw}{ds} = \frac{1}{D}\left\{(Q\frac{e_2}{[1-s]^2} + w)\frac{\partial e}{\partial u} + M(\frac{e_2}{[1-s]^2} + \frac{\partial e}{\partial s})\right\} \phi\ 0 \qquad (29)$$

where $M = L_r(\ l - 1 + w(1-s))/(\frac{r}{e} + (1-u)L_r)$ >0. (29) implies that the subsidy tends to spill-over into a positive wage effect benefiting the R&D workers.

To see the effects on equilibrium effort we first note from (9) that the increase in s lowers the value of the second argument in the effort function which tends to raise effort. This positive impact effect on effort occurs since s lowers the expected returns from doing R&D which in our fair wage framework stimulates effort. The general equilibrium effects are:

$$\frac{de}{ds} = \frac{1}{D}\left\{(\frac{e_2}{[1-s]^2} + e_1 w)\frac{\partial e}{\partial u} + M(\frac{\partial e}{\partial w_1}\frac{e_2}{[1-s]^2} + e_1\frac{\partial e}{\partial u})\right\} \phi\ 0. \qquad (30)$$

As u falls, effort tends to go down but counteracting this effect is the direct effect on effort of an increase in s and the increase in R&D workers' wage.

Somewhat surprisingly, we find that the subsidy not only stimulates firms to hire more R&D workers in the labs but also that it stimulates each R&D workers' effort. Consequently, the growth rate unambiguously goes up. Hence, in an efficiency wage model of the fair wage variety there is an added positive growth effect emanating from more effort due to higher relative wages of the R&D workers.

We noted though that expenditures go down. With positive growth effects and negative effects on expenditures, we cannot sign the welfare effects.

Effects of productivity increases.

We may interpret an increase in l as an increase in productivity since this parameter, for given inputs in efficiency units, raises the increase in quality improvement. If each research breakthrough implies a larger step on the quality ladder, we should expect firms to allocate a larger share of R&D workers to the lab. Indeed, this is the case since u drops:

$$\frac{du}{d\,l} = -\frac{1}{D}\left\{\frac{w(1-s)}{r + e(1-u)L_r}(e_1 + \frac{\partial e}{\partial w})\right\} \pi\ 0 \qquad (31)$$

which, from (11), implies that λ rises. The fact that u falls implies that effort tends to fall and to restore equilibrium, firms revise the wage rate upwards:

$$\frac{dw}{d\,l} = \frac{1}{D}\left\{\frac{L_p + uL_r}{\frac{r}{e} + (1-u)L_r}\,\frac{de}{dl}\right\} \phi\ 0, \tag{32}$$

and, in equilibrium, the net effect on effort comes out positive:

$$\frac{de}{d\,l} = \frac{1}{D}\left\{e_1\,\frac{L_p + uL_r}{\frac{r}{e} + (1-u)L_r}\,\frac{de}{dl}\right\} = e_1\,\frac{dw}{d\,l}\ \phi\ 0. \tag{33}$$

The effect on growth is unambiguously positive and for three reasons. First, a higher l does itself have a directly positive growth effect since $g = e\lambda \log\ l$. Secondly, λrises and; thirdly, each R&D worker increases effort. Moreover, expenditures go up as $\frac{dE}{d\,l} = \frac{du}{d\,l}L_r(1-w+ws) + \frac{dw}{d\,l}(1-s)(L_r(1-u) + \frac{r}{e}(1-we_1))\ \phi\ 0$ for reasonable values of the R&D subsidy. Hence, as both growth and expenditures go up, the effect on welfare is unambiguously positive.

Table 1 summarizes our findings. In general the growth effects are unambiguous, though we in three out of four cases obtain ambiguous effects on welfare per worker.

Table. 1. Effects on endogenous variables of changes in exogenous variables and parameters. +- = ambiguous effects. $e^{e}_{L_r}$ =elasticity of effort with respect to L_r and $e^{\lambda}_{L_r}$ =elasticity of R&D inputs with respect to L_r

	R&D inputs, λ	**Effort, e**	**Growth, g**	**Wage rate, w**	**Under utiliz. of R&D, u**	**Expendi-ture/ worker**	**Welfare/ worker**
$\Delta L_r > 0$	+	-	$\frac{\pm}{-} if e^{e}_{L_r} \frac{\phi}{\pi} e^{\lambda}_{L_r}$	-	+	+-	+-
$\Delta L_p > 0$	+	+	+	+	-	+-	+-
$\Delta L_r > 0$and $\Delta L_p < 0$	+-	-	+-	-	+	+-	+-
$\Delta s > 0$	+	+	+	+	-	-	+-
$\Delta\, l > 0$	+	+	+	+	-	+	+

4. Concluding Remarks

Much of the growth literature focuses on firms' incentives to employ R&D workers as the driving force of economic growth and the qualitative aspects of the R&D inputs in firms have consequently been much neglected. We have therefore analyzed a growth model in which the individual R&D worker determines effort based on fair wage considerations for which we have argued there exist ample empirical evidence. Our results are consistent with the stylized fact that the growth rate need not rise to the extent predicted by basic endogenous growth theory. In our model, when the supply of R&D workers increases over time, not only does this raise the under utilization rate of R&D workers, but it also tends to reduce the work effort of R&D workers. The growth effects of increases in R&D workers are theoretically ambiguous and if the adverse effects on effort are large enough, the growth rate drops. Though we argued that a negative effect not necessarily is a likely outcome in real economies, changes in work effort may, nevertheless, inhibit the growth process limiting the positive effects of increased R&D inputs.

Moreover, it is striking that a corresponding adverse effect does not show up as the number of production workers rises. Our model casts yet more doubts on the favorable growth effects of higher education. As production workers become R&D workers a large number of growth inhibiting effects show up: Several mechanisms lower effort as well as the share of R&D workers employed in the labs. These effects have no room in comparable growth models based on competitive wage setting which for this reason can be argued to exaggerate the growth effects of higher education. Moreover, the fact that human capital trends upwards and growth rates do not for the OECD countries, is one reason why Jones (1995a) reject the so called "AK"-style growth models of Romer, while the observation is easily explained in our model.

Can we realistically believe that changes in R&D workers' effort can be of such a magnitude that long run increases in the number of R&D workers do not materialize in higher recorded growth rates? OECD countries have experienced large increases in L_r and consequently also increases in R&D inputs, λ, as predicted by our model. Jones (1995a) showed that the increases in λ, i.e. the actual number of R&D workers employed in the labs, have not yielded the expected growth effects. That increases in λ do not affect the growth rate g can in our model only be explained by large adverse effort effects. Data on workers' effort are not collected by statistical bureaus which makes an empirical evaluation very hard. But much evidence suggest that changes in effort may matter. As noted in the introduction there are convincing evidence that sociological and psychological aspects in the form of fair wage considerations matter to workers' behavior. Nor can we realistically doubt that the firms that participate in R&D races should have very strong incentives to extract top performance out of their R&D workers in the laboratories. Firms also go a long way to find compensation policies that serve the purpose of stimulating hard work, particularly among workers in key positions. There are also evidence, albeit much of an anecdotal nature, that people work very hard in the tiger economies. Though we do not necessarily believe that long run changes in effort are highly important, the existence of adverse work morale effects might still be one part of the explanation why it is difficult to empirically trace the growth effects of increases in the physical number of R&D workers in the high income countries.

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APPENDIX

The equation system (7) through (11) may first be simplified by solving for E in (11) and plugging the result into (7) and similarly eliminating λ. This yields the following three equation system that, by means of standard methods, solves for w, e and u:

$$\frac{(l-1)\left[L_p + uL_r\right]}{r/e + (1-u)L_r} = w(1-s)$$

$$e = e_1 w + \frac{e_2}{(1-s)}$$

$$e = e(w, (1-s), u)$$

Differentiating with respect to w, e and u yields:

$$\begin{bmatrix} -(1-s) & \dfrac{(\frac{r}{e^2}(l-1)(L_p + uL_r)}{(\frac{r}{e} + (1-u)L_r)^2} & \dfrac{L_r(l-1+w(1-s))}{\frac{r}{e} + (1-u)L_r} \\ -e_1 & 1 & 0 \\ -\dfrac{de}{dw} & 1 & -\dfrac{de}{du} \end{bmatrix} * \begin{bmatrix} dw \\ de \\ du \end{bmatrix} =$$

$$\begin{bmatrix} \dfrac{-(l-1)\left[u/e-(1-u)L_p\right]}{\left[r/e+(1-u)L_p\right]^2} dL_r & \dfrac{-(l-1)}{r/e+(1-u)L_r} dL_p & -wds & \dfrac{w(1-s)}{r+(1-u)L_r} dr & \dfrac{-\left[L_p + uL_r\right]}{r/e+(1-u)L_r} dl \\ 0dL_r & 0dL_p & \dfrac{e_2}{(1-s)^2} ds & 0dr & 0dl \\ 0dL_r & 0dL_p & \dfrac{de}{ds} ds & 0dr & 0dl \end{bmatrix}$$

The solution implies a positively signed determinant:

$$D = (1-s)\frac{de}{du} + \frac{e_1 \frac{ar}{e^2}(l-1)(L_p + uL_r)}{\left[\frac{r}{e} + (1-u)L_r\right]^2} \frac{de}{du} + \frac{e_1 L_r (l-1+w(1-s))}{\frac{r}{e} + (1-u)L_r} + \frac{de}{dw}\frac{1}{e_1}\frac{L(l-1+w(1-s))_r}{\frac{r}{e} + (1-u)L_r} \phi \; ($$

and when solving the model with standard methods, the results reported in the text obtain.

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